FDG imaging of 1mm tumor with an ultra high resolution animal PET

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Abstract

Recently, we reported an animal semiconductor PET with the spatial resolution of 0.8mm FWHM within the central 20mm-diameter of FOV for the purpose of biomedical study using rats and mice. This ultra high spatial resolution was obtained by the use of small CdTe elements of 1.1mm × 1.0mm × 5mm. The FOV of this PET is 64mm in diameter and 26 mm in axis. We applied to observe small tumors in mouse and succeeded to obtain [^{18}F]FDG images of mouse mammary carcinoma of ~1mm size.

Keywords: positron emission tomography

1. Introduction

The mortality rate of cancer is highest among serious critical diseases. However, if the cancer can be found at a very early stage, for an example, a tumor of 1mm size, it is not so scary. Therefore, it is desired to develop a high spatial resolution PET which can find very small tumors.

The spatial resolution of positron emission tomography is generally limited by the spatial distribution of positrons emitted from radioisotopes, the angular fluctuation of positron-electron annihilation gamma rays and the size of gamma ray detectors. The width (FWHM) of positron distribution can be estimated less than 0.2mm in the case of ^{18}F. This factor does not influence the spatial resolution of PET. The spreading effect of annihilation γ-rays due to their angular distribution can be suppressed by shortening the diameter of detector ring. Figure 1 shows the calculated spatial resolution of PET using ^{18}F as a function of diameter of detector ring where the size of detector is assumed to be zero. It is shown in Fig. 1 that the spatial resolution (FWHM) of PET can be achieved less than 1mm for a small diameter of gantry. Therefore, the most effective factor to improve the spatial resolution is to downsize the detector. The present best spatial resolution (FWHM) in scintillator PETs is 1.1-mm FWHM at the center of FOV and less than 2 mm FWHM within the central 4-cm-diameter of FOV [1-3]. This resolution will be the limit obtained

by the use of scintillation detectors. On the other hand, the semiconductor detector can be downsized in mm scale which allows a high spatial resolution of less than 1mm FWHM for PET. Several semiconductor detectors namely Si, Ge, GaAs, CdTe, CZT and so on are nominated for the detector of PET. We developed recently a very high resolution animal PET using CdTe detectors [4] and tried to observe a tumor of 1mm in a mouse with FDG PET. Here, we present the performance of our semiconductor PET and the observation of 1mm tumors.

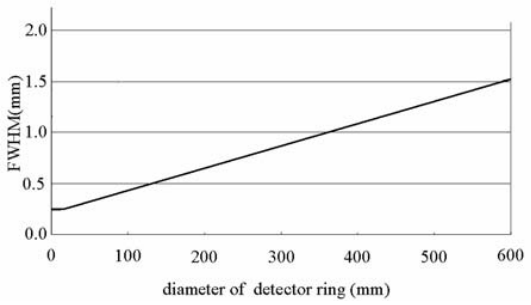


Fig.1. Spatial resolution of PET using ^{18}F as a function of diameter of detector ring.

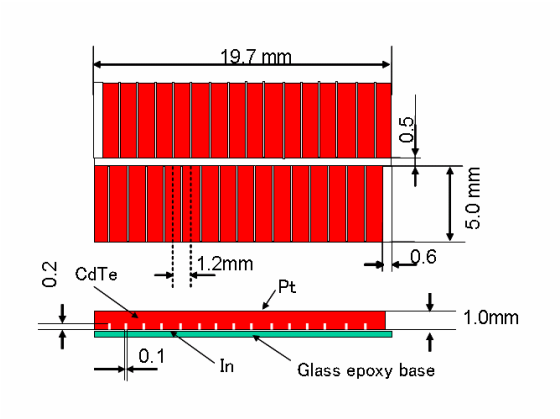


Fig.2 Schematic view of CdTe strip detector unit.

2. Ultra high resolution semiconductor animal PET

We adopted the Schottky barrier diode CdTe detector with In and Pt electrodes[5], which gives a good S/N ratio, an adequate time resolution (~ 6n sec FWHM) for the coincidence measurement in PET and also a high sensitivity for 511keV γ-rays. This detector has the property of the polarization effect but it could be recovered by the reset of detector bias. Figure 2 shows a schematic view of CdTe strip detector unit composed with two arrays of 16 CdTe detectors(1.1mm × 1mm × 5mm) respectively separated with a track 0.1mm width × 0.2mm depth. The rear array is shifted by a 0.6mm to the front one. Owing to this arrangement, three cross LORs can be allowed in the interval of 1.2mm and the data sampling for the tangential axis of sinogram can be done by the step of 0.3mm. The structure of two detector layers allows the DOI information. This detector array can provides fine structure images of PET and we call our high resolution semiconductor PET "Fine PET". The detection efficiency of detector unit (CdTe 10mm thick) is 0.41 for 511 keV γ-rays. The packing ratio of detector bucket which consists of 16 detector units is 0.56. The detector gantry consists of 10 detector buckets and its bore diameter is 70 mm. 32 signal lines from the detector unit connect with 32 ASIC amplifiers mounted on one board. Figure 3 shows the detector arrangement and photographs of detector gantry.

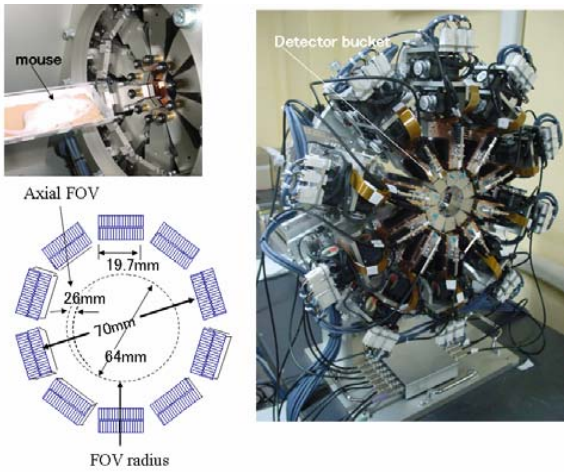


Fig.3 Photographs of Detector Gantry

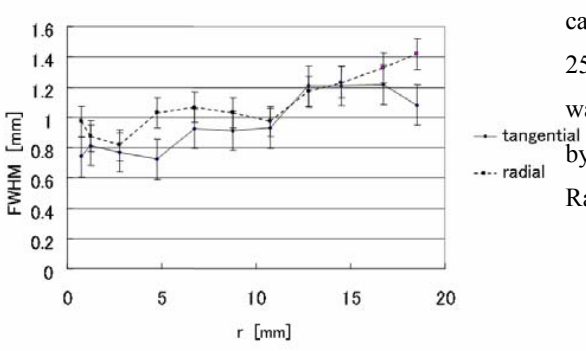


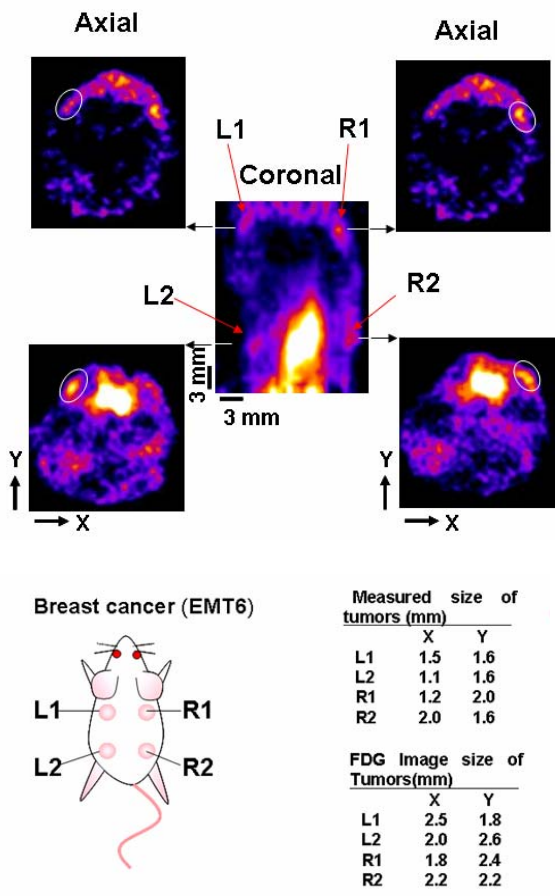
Fig.4 Spatial resolutions as a function of the distance r from the center of FOV (right)

One ASIC chip contains 32 preamplifiers and 16 the ASIC chips are mounted in one detector bucket. Event signals are amplified in ASIC and only the signals above a threshold level are sent to FPGA. The threshold level can be changed with a host computer and was set at 215 keV in this work. FPGA encodes the detection time of γ-ray with the clock signal of 100MHz. Due to this clock performance, the coincidence time window of PET is limited by 20 n sec. The host computer determines the LOR using the data of detection time and detector position from FPGA and forms sinograms which are sorted in a list mode. The image reconstruction using Maximum-Likelihood Expectation-Maximization (ML-EM)[6] method is carried out by another personal computer.

^{22}Na point source of ~ 0.5mm diameter was used to measure the spatial resolution. Figure 4 shows the spatial resolution as a function of distance from the center of gantry. The tangential resolution is 0.74 mm FWHM at the center of FOV. The tangential and radial resolutions are smaller than 1mm in the regions of 22mm and 10mm diameter, respectively. The sensitivity of our PET is 40cps/kBq/ml.

3. Observation of 1mm tumors

We measured the [^{18}F] FDG images of a mouse with small tumors which is mouse mammary carcinoma (EMT6). A male BALB/c mouse (7 weeks, 25g) was used in this work. The animal experiment was carried out according to the protocol approved by the Animal Care Committees of Cyclotron and Radioisotope Center, Tohoku University.



Measured size of tumors (mm)

	X	Y
L1	1.5	1.6
L2	1.1	1.6
R1	1.2	2.0
R2	2.0	1.6

FDG Image size of Tumors(mm)

	X	Y
L1	2.5	1.8
L2	2.0	2.6
R1	1.8	2.4
R2	2.2	2.2

Fig.5. Coronal and axial views of FDG images of small tumors.

The tumor cells of 2×10^6 and 5×10^5 were transplanted at the position of L1 and L2, and R1 and R2 (see Fig.5) on the back, respectively. After 2 days, the mouse was injected intravenously with 77.7 MBq (2.6 mCi) of [^{18}F]FDG in 0.2 ml of physiological saline via tail vein. After 60 minutes of [^{18}F]FDG injection, the mouse was anesthetized with 1.5% isoflurane. Then, PET scanning was carried out for 120 minutes. Figure 5 shows the coronal and

axial views of mouse body which were obtained by the method of FORE[7] + ML-EM (30 iterations). After PET scanning, immediately we measured the real size of tumors which are shown in Fig.5. As seen in Fig.5, the FDG images of tumors of 1.1~2.0 mm size can be clearly recognized at the positions of R1, R2 and L2. At the position of L1, the tumor can be also found though the accumulation of FDG was a little.

4. Conclusion

We have developed the high resolution semiconductor PET with 0.74mm FWHM. We applied to observe tumors of 1mm size with our PET and succeeded to obtain the fine FDG images of very small tumors. Our PET is now being used for mice and rats imaging studies in our medical research group.

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